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High-Performance InGaAs Metal-Semiconductor Field Effect Transistors for Optoelectronic and High-Speed IC's

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ABSTRACT

We report here novel InGaAs MESFETs using enhanced Schottky barrier gates for the integration of electronic and optical devices on InP substrate. Metal gates, placed on top of Langmuir-Blodgett deposited thin-film or lattice-mismatched semiconductor, have been used to enhance the Schottky barrier height. High-performance MESFETs and MSM detectors using 1 μm gate technology were fabricated and analyzed.

1. INTRODUCTION

The ternary alloy InGaAs is an important material for monolithic integration of Field-Effect-Transistors (FET's) and optical devices, such as metal-semiconductor-metal (MSM) photodetectors, for fiber-optic communications because of its superior electron transport properties and ability to absorb radiation in the 1.3-1.55 μm wavelength range.[1-4] However, in spite of favorable electrical and optical properties, performances of simple Schottky contact on InGaAs for MESFETs and MSM detectors are poor due to low Schottky barrier heights of metals on n-InGaAs. MISFET and JFET, requiring more demanding device processing techniques, have been studied as alternative devices. Both devices show less than ideal performance due to high parasitics in the case of JFET and a high density of interfacial states in the case of MISFET. We have fabricated enhanced Schottky barrier devices which are excellent candidates for the integration of structurally compatible MESFETs and MSM detectors.

We report here novel MESFET structures using enhanced Schottky barrier gates on n-InGaAs with low gate leakage current, high transconductance, and high drain current.[5-6].

2. DIELECTRIC THIN-FILM GATE

We have fabricated a MESFET with a metal gate on dielectric thin film formed by Langmuir-Blodgett (L-B) deposition [7] of multiple monolayers of the cadmium di-stearate followed by an oxygen plasma etch. The epitaxial layers, grown by organometallic chemical vapor deposition on InP substrate, consist of a 10 nm undoped InP buffer layer, a 250 nm InGaAs channel with 6 x 10^{16}

cm $^{-3}$ Te doping and a 100 nm n^+ InGaAs cap with a doping > 10^{18} cm^{-3}, as indicated in Fig. 1. The FET mesa was formed by argon ion milling. Source and drain contacts were made with AuGeNi alloyed at 420 °C for 20 seconds. After aluminum gate deposition and lift-off, a final metal layer of TiAu was deposited to form the bonding pads to complete the device processing.

An enhanced barrier height of 0.52 eV and a leakage current of 0.4 A/cm^2 at -2.5 V with 100 monolayers of L-B film were measured. From Auger analysis of the plasma etched thin film and diode I-V characteristics, we conclude that the Schottky barrier is dielectric-enhanced.[8)] The thin film contains a mixture of cadmium oxide, carbonate and other compounds; no metallic cadmium was observed. This gate differs from an insulator gate in that it is conducting under forward bias and blocking under reverse bias rather than blocking under either bias.

This InGaAs MESFET had a maximum extrinsic transconductance, g_m, of 160 mS/mm and a pinch-off voltage of -1.8 V. The average g_m was about 150 mS/mm throughout the gate operation range of 0.0-1.75 V, as illustrated in Fig. 2. High average g_m transistors are important for digital ICs to maintain fast switching speed even at the presence of large input voltage swings. With a measured source resistance of 2.1 Ω/mm, the intrinsic transconductance is estimated to be 270 mS/mm. The saturation velocity of the carriers in the channel [9)] was measured to be higher than 3.5 x 10^7 cm/s which is comparable to the highest value reported in the literature. The drain current I_{dss}, 300 mA/mm at V_{ds}= 2.5 V, as shown in Fig. 3, is the highest current reported for 1 μm gate length depletion-mode InGaAs MESFET devices.

3. <u>SEMICONDUCTOR-ASSISTED GATE</u>

In addition, we have fabricated MESFETs and MSM photodetectors with semiconductor assisted Schottky gates [10-11)] using undoped thin layers (30 nm) of lattice-mismatched $Al_xGa_{1-x}As$ ($0 \le x \le 0.15$) or lattice-matched InAlAs on InGaAs to enhance the Schottky barrier height. Fig. 4 shows OMCVD grown epitaxial layers on InP substrate. The n-InGaAs channel of MESFET has about 1.3 x 10^{17} cm^{-3} doping and with a channel thickness of 120 nm. MSM detectors were made with epitaxial layers similar to the MESFET shown in Fig. 4, except the n-channel was replaced by a 1 μm, undoped InGaAs absorption region. To simplify the fabrication process, we did not include a n+ InGaAs cap layer for source and drain contact. Again, ion milling for mesa etch, AuGeNi alloy for source and drain contacts, and TiAu for the gate electrode were used in device processing.

The extrinsic transconductance of InGaAs MESFETs with AlGaAs top layer was 150 mS/mm and the gate pinch-off voltage was -1.8 V. The gate to drain break down voltage was 6 V. A level shifting diode for digital circuit was also studied. The knee-voltage was about 0.7 V at 0.5 mA forward current.

Our latest results showed a MSM gate leakage current of 0.1 A/cm^2 at -5 V bias for $Al_{0.15}Ga_{0.85}As$/InGaAs structure. This is a factor of four times improvement over the lattice matched InAlAs/InGaAs and the previously discussed L-B deposited gate structures. We attribute this low leakage current to higher effective barrier height due to the larger bandgap of the lattice-mismatched AlGaAs layer. Fig. 5 shows the optical pulse response of this low leakage MSM detector biased at 15 V. A pulse width of 70 ps (FWHM) was measured with no appreciable diffusion tails. This is sufficient for multi-gigabit/s digital signal detection. The MSM detector also achieved a very linear responsivity of 0.4 A/W at 1.3 μm wavelength. No low frequency noise was observed.

4. CONCLUSIONS

With enhanced Schottky barrier technologies, we have fabricated InGaAs MESFETs with high drain current, high transconductance, and low pinch-off voltage. These techniques have also been employed to fabricate high-performance MSM detectors with low leakage currents. We conclude that these technologies are suitable for low noise optoelectronic and high-speed digital IC applications.

5. REFERENCES

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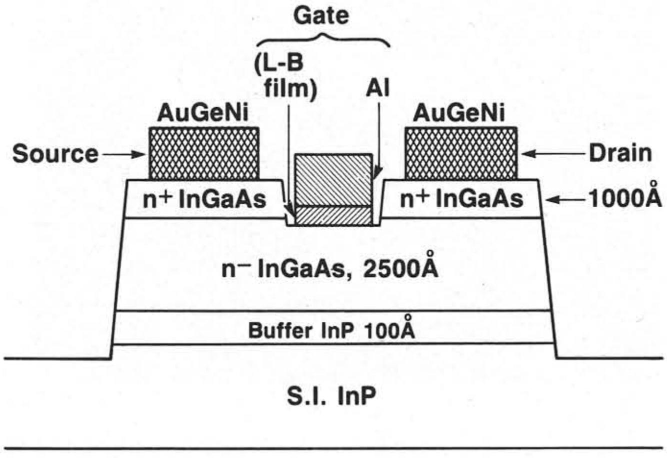

Fig. 1 Cross section of InGaAs MESFET with Langmuir-Blodgett deposited dielectric thin-film gate.

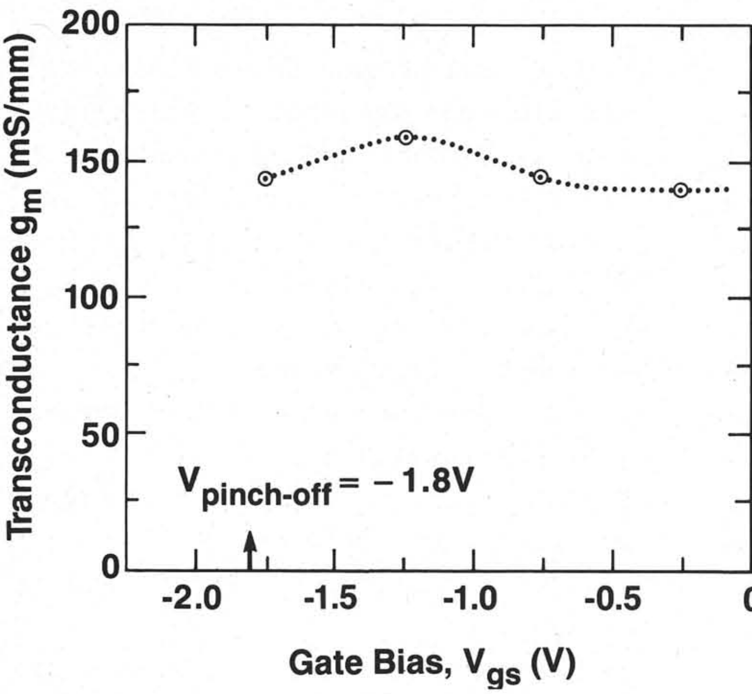

Fig. 2 Extrinsic transconductance, g_m, of InGaAs MESFET with L-B deposited thin-film gate.

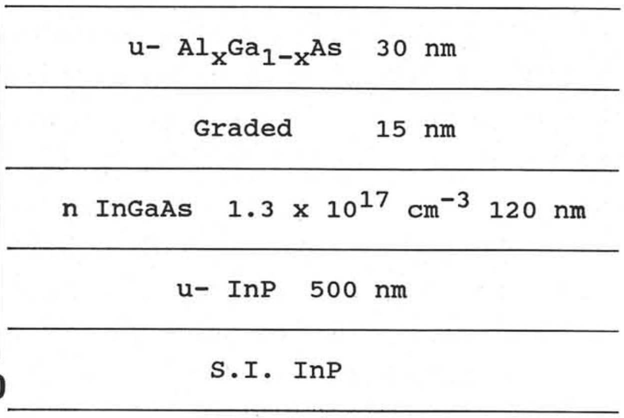

Fig. 4 Cross Section of InGaAs **MESFET with** AlGaAs assisted Schottky gate.

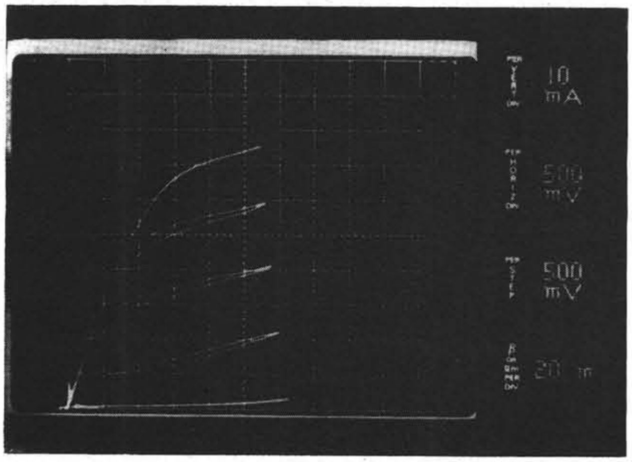

Fig. 3 Drain-source I-V characteristics of InGaAs MESFET, l_W=250 μm, V_{gs} = 0-2.0 V, 500 mV per step.

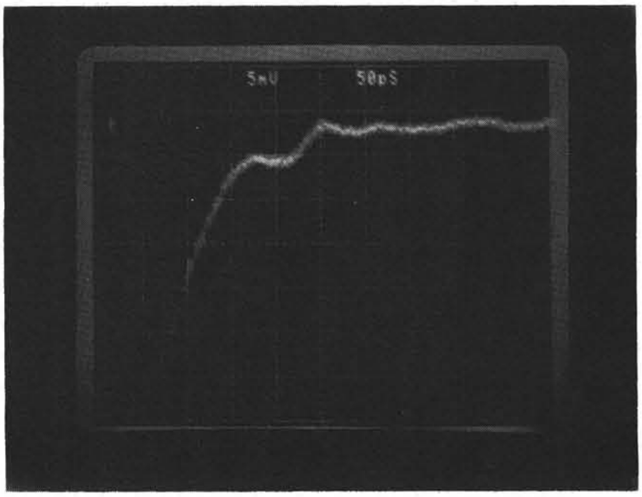

Fig. 5 Optical pulse respon**se of AlGaAs**/InGaAs MSM detector bia**sed at** 15 V, 50 ps/Div..